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ARS SPECIAL REPORT

A Universal Equation for Predicting Rainfall-Erosion Losses--

An aid to conservation farming in humid regions

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SUMMARY

ARS scientists have developed a soil-loss predicting equation that promises to be a significant contribution to safe, productive use of the Nation's soil. The equation's chief merit is versatility--it can be used wherever rain causes significant erosion losses. Its value in predicting longtime, localized soil losses has been established. It can be used to define the conservation practices needed for a given field to limit soil losses to tolerable levels. It provides a mathematical approach to conservation farm planning.

Research is continuing to improve the equation, to increase the accuracy of its factors, and to extend its scope and usefulness.

This report describes how research into the factors of rainfall erosion has resulted in the development of a practical equation. Also, it explains how the equation works.

Information in this report was provided by the Soil and Water Conservation Research Division, Agricultural Research Service

A UNIVERSAL EQUATION FOR PREDICTING RAINFALL-EROSION LOSSES--

An Aid to Conservation Farming in Humid Regions

GIVEN: A cropped field in the continental United States that is susceptible to significant rainfall-erosion losses.

NEEDED: Conservation practices and a cropping and management program that will limit soil losses from this field to a level that will not reduce its future production potential.

PROBLEM: How to select practices that will permit a farmer to make the most profitable use of the field and still protect and improve the soil.

SOLUTION: A new soil-loss predicting equation, called the Universal Equation, solves problems of this type almost as easily as the terms of the problem can be written down.

Like other worthwhile achievements, the new equation evolved from relatively modest beginnings and owes its present state of perfection to the work of many individuals.

HISTORICAL HIGHLIGHTS

Scientists generally agree that control of a mechanical or physical process is not usually successful unless the process is understood. And understanding generally comes only when the factors that influence the ultimate effect of the process can be measured and the measurements considered together in an equation.

Soil erosion caused primarily by rain is one of these processes. The factors that influence it, besides rain, are the particular soil type, the length and percent of slope, the cropping and management, and the applied conservation practices. Concentrated efforts to measure the influence of each of these factors on soil loss--and to relate each to the others--began in the United States in 1929 when soil conservation scientists began collecting basic rainfall-erosion data. As tentative measurements slowly emerged from considerations of this data, equations and methods to predict rainfall-erosion losses were formulated. None of these, however, until the Universal Equation was published, was universally applicable to all areas where soil loss because of rain is significant.

Equation Development in the North Central States

In 1940 an equation that related relative soil loss to length and percent of slope was published. This equation utilized all rainfall-erosion data then available in the United States. It is usually considered the pioneering effort to put soil conservation on a firm, quantitative basis.

In 1941 factors to express the influences of cropping and conservation practices on soil loss and the soil-loss tolerance concept (see page 9)

were added to the initial equation. The equation was developed for applying conservation practices to Shelby and associated soils of the Midwest.

Between 1941 and 1946 further improvements were made in the equation for use throughout Iowa by adding factors to express the influence of soil type and quality of management on soil loss. Similar developments were made in Missouri for the Midwest claypan soils and later for other principal soils of Missouri.

In the meantime research and operational conservationists of the Soil Conservation Service, U. S. Department of Agriculture, in the eight North Central States, developed the system now referred to as slope-practice for use in farm planning in their area.

Other Developments

In 1946 a group of scientists reviewed all soil-loss data then available in the United States, reevaluated the equation factors up to that time, and added a rainfall factor. The results of this work were published in 1947. In 1952 a group of charts were prepared so the equation could be used in the Northeastern States.

The New Equation

In the fall of 1956 ARS scientists concentrated their efforts on developing a soil-loss predicting equation that could be universally applied wherever rain causes significant erosion losses. The equation that ultimately emerged from this research improves localized, soil-loss predictions without drastically changing basic concepts and application procedures. It retains some of the features of the earlier equations. A new way of evaluating the erosive effects of rain is its backbone and accounts for most of its versatility.

The new way of evaluating the erosive effects of rain emerged when 8,000 plot years of basic erosion data were analyzed by the ARS National Runoff and Soil Loss Data Laboratory at Lafayette, Ind., and the Purdue University Agricultural Experiment Station, cooperating. At the present time, 166 U. S. Weather Bureau and 15 ARS installations have supplied the rainfall data needed to extend the scope and usefulness of the equation.

Although the equation is empirical,[1] its value for estimating longtime, average annual rates of erosion or in applying conservation practices that limit soil losses to tolerable levels has definitely been established.

As rainfall data from the U. S. Weather Bureau and ARS installations are collected and processed, ARS will prepare the technical publications needed to use the equation in individual geographic areas where rainfall erosion problems are similar. These publications will include iso-erodent maps (fig. 1), rainfall erosion index distribution curves (fig. 3), and tables or charts of numerical evaluations for the factors other than rainfall. The new equation is currently being introduced at workshops,

[1] An equation that is satisfied by a given set of corresponding values of variables furnished by statistical study or laboratory measurements. It is arrived at by trial and judgement rather than by a theoretical approach. Empirical equations are extensively used in scientific computations when satisfactory theories of phenomena are not available. Sometime they are important steps toward the establishment of theories and physical laws.

sponsored jointly by SCS, ARS, and State experiment stations. Reports of the proceedings of the workshops are distributed as further aids to the understanding of the equation. Thus, Soil Conservation Service technicians, farm planners, and agricultural leaders generally can look forward to having a potent new tool to aid them in their conservation and educational work.

FACTORS IN THE NEW EQUATION

The new equation reflects the influence of all the major factors known to influence rainfall erosion. It is as follows: A = RKLSCP.

A is the average annual soil loss in tons per acre predicted by the equation.

R is the rainfall factor.

K is the soil erodibility factor.

LS is the length and steepness of slope factor.

C is the cropping and management factor.

P is the supporting conservation practice factor (terracing, strip-cropping, contouring.)

How these factors affect erosion and how numerical equivalents for them were established, are discussed in the sections that follow. Also discussed are soil-loss tolerance values, which help make the equation more practical. A concluding section shows how the equation has been used to resolve a typical farm erosion problem.

The Rainfall Factor (R)

Three or four rainstorms often cause as much as three-fourths of a year's soil loss from row crops. On Cecil sandy loam in Georgia, 26 storms caused 54 percent and 52 storms caused 74 percent of the 13-year total soil loss from continuous cotton contoured on a 7-percent slope. On Fayette silt loam in Wisconsin 12 storms accounted for 60 percent of the 6-year total soil loss from continuous corn contoured on a 16-percent slope. Two-thirds of the total 20-year loss from continuous corn planted up and down a 9-percent slope on Marshall soil in Iowa resulted from 40 storms. On Bath flaggy silt loam at Ithaca, N. Y., three-fourths of the 10-year soil loss from corn contoured on a 12-percent slope was associated with 20 rainstorms. It is therefore necessary to know the value of the relatively few storms that cause the lion's share of field erosion and to know at what time in the year they are most likely to occur in each specific geographic region.

Observations of this type, however, have little value unless the characteristics of rain responsible for its erosive potential can be identified, measured, and the likelihood of their recurrence determined. In 1958, two ARS scientists pinpointed one of these characteristics. They developed a method of computing the energy of rainfall and correlated this characteristic with erosion from cultivated fallow soil. Rainfall energy was expressed in foot-tons per acre inch--for example, a rain

falling at the rate of 1 inch per hour for an hour on an acre of land has enough energy to lift 916 tons of soil 1 foot. However, rainstorm energy alone did not correlate well enough with soil loss to be considered a satisfactory measure of the potential of rainfall to cause erosion. After further investigation of many combinations of rainfall characteristics and interaction effects, the scientists identified a second characteristic--a rain's energy times its maximum 30-minute intensity. This product is the truest indicator yet developed to measure the potential of rainfall to cause erosion from cultivated fallow soil.

This combination or product (total energy times maximum 30-minute intensity) explained from 72 percent to 97 percent of the variation in individual storm losses from tilled continuous fallow soils in Missouri, Iowa, Wisconsin, Ohio, New York, and South Carolina. When tested against the data from plots in continuous row crop for 10 years or more at four other widely separated locations, the energy-intensity products explained from 72 percent to 85 percent of the variation in soil loss within corresponding cover periods.

The product total storm energy times maximum 30-minute intensity have been computed for those rains above an established minimum for as many localities as possible where U. S. Weather Bureau or other records from recording gages for continuous periods (usually, 22 years) were available. The individual values were then divided by 100 to make them more convenient to handle and to define a rainfall erosion index. When all the storm indexes for a locality are added together and divided by the years of record, an average annual index emerges that is reasonably valid for use in the erosion equation.

The 181 indexes thus far calculated for various localities within the U. S. have been used to establish on a map iso-erodent lines--lines that connect points considered to have the same index (fig. 1) or equally erosive average annual rainfall.

The approximate range of average annual indexes for different regions where rainfall erosion is a problem is as follows: Southeastern States, 142 to 779; Northeastern, 62 to 220; and North Central, 64 to 261.

The Soil Erodibility Factor (K)

This factor reflects the fact that different types of soil erode at different rates when the other factors affecting erosion are constant. Certain physical characteristics of a soil apparently affect the rate--for example, sandy soils generally are more susceptible to erosion than clay soils if runoff is equal. But the rate of erosion is also affected by the amount and rate of runoff and how much erosion, if any, has already occurred in the field under study. Experimental results and field observations supporting these facts come from many widely scattered locations.

The influence of soil type has so far been evaluated for eight soils for which fallow plot data has been available. The values are expressed as tons of soil loss per acre per unit of rainfall index from tilled continuous fallow for a slope of specified dimensions. This means that an unprotected, "standard" slope (see last paragraph, next section) would erode at an established rate in tons of soil per acre for each unit of rainfall-erosion index for the locality. If the index were 240, the amount of soil eroded would be the rate in tons per acre times 240.

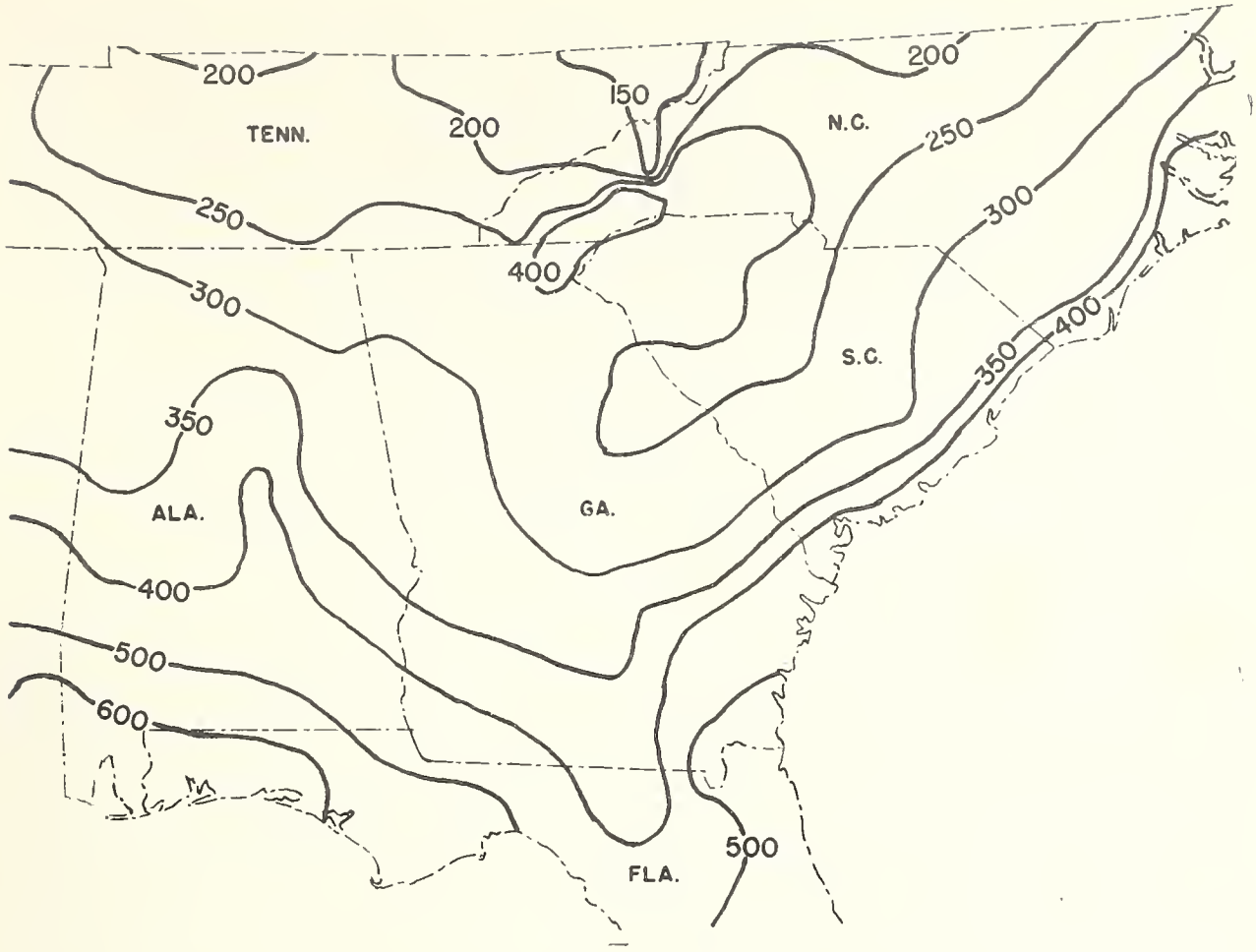

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Figure 1.--Map of Southeastern United States showing iso-erodents--lines connecting points that have the same average annual rainfall erosion index. The identifying number on each iso-erodent is the rainfall erosion index along the path of that line.

Many of the soil erodibility values now in use were arrived at by scientific judgment--by considering a soil's characteristic and by tempering the estimate of its erodibility against the established values for the eight soils.

Increased research effort on soil erodibility is planned for the next several years to define this equation factor more precisely. Studies will be conducted at the ARS Laboratory at Lafayette and at other locations where field and laboratory rainfall simulators are available.

The Length and Steepness of Slope Factor (LS)

Research extending back to 1929 shows that soil loss per unit area increases as slope length or steepness of slope increases but not at uniform rates.

These slope relationships are not yet considered entirely satisfactory. For example, some soil-loss data indicate that significant interactions exist between length and steepness of slope, row direction, soil characteristics, and the erosion index of particular rains. These remain to be

evaluated in current studies at the ARS Laboratory at Lafayette and at other locations.

Evaluations now used for these variables are ratios of loss for any steepness and length of slope with the arbitrarily selected standard being a 9-percent, 73-foot slope. If the standard has a value of 1, for example, a 9-percent, 200-foot slope would have a value of 1.7 and 1.7 would be used in the equation if erosion from such a slope was being investigated. These and other slope length-steepness ratios are presently determined from a chart, like the one that is figure 2.

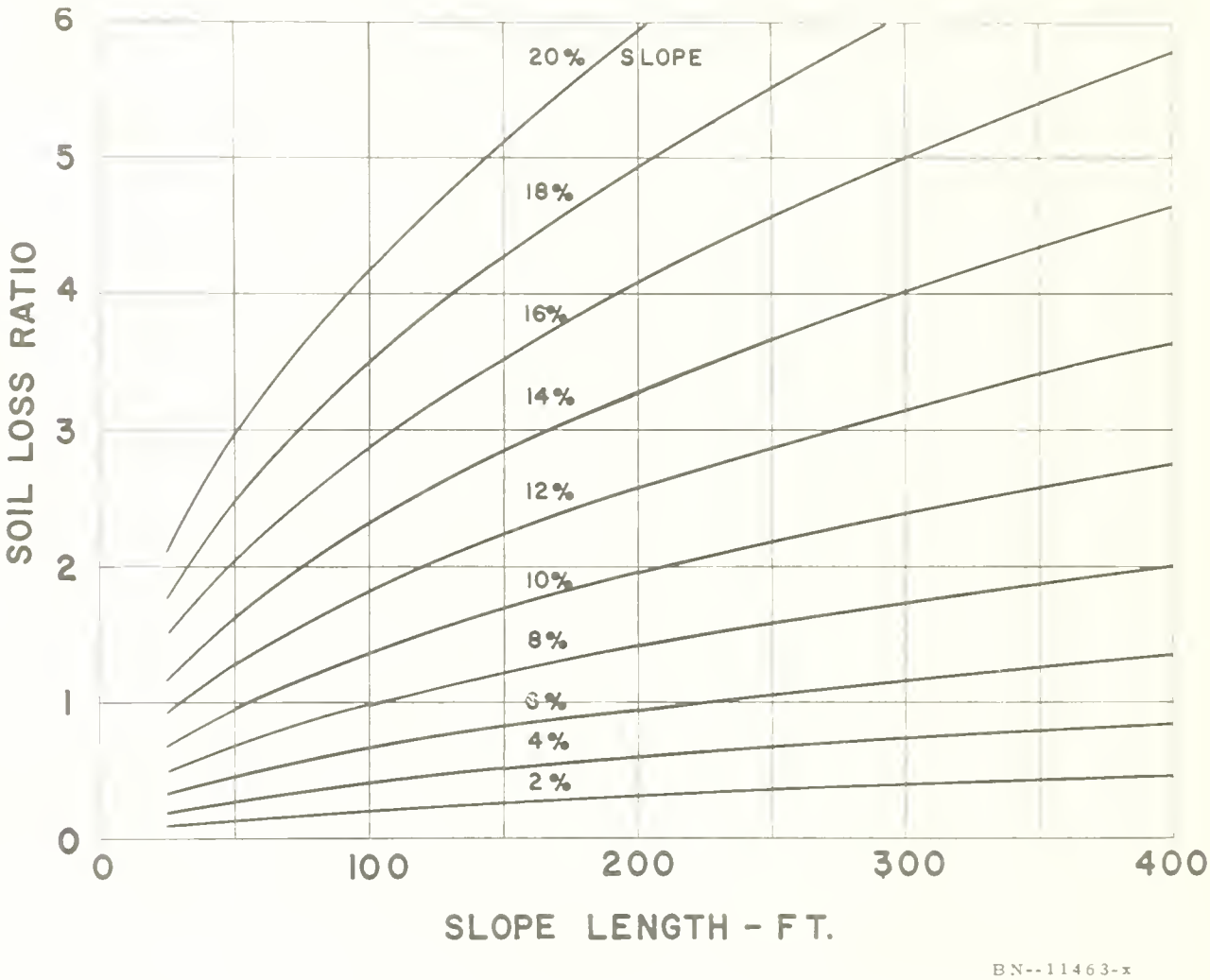

Figure 2.--Chart for adjusting plot soil loss to length and steepness of slope.

The Cropping and Management Factor (C)

This factor has been difficult to evaluate because of the many ways that land can be cropped and managed and because of other considerations such as rate and amount of crop growth. For example, almost any crop can be grown continuously, or it can be grown in a rotation. Rotations can be varied and the sequences of crops within them can be varied. In addition, residues can be removed or left on a field and manure or mineral fertilizer added. All in all, 100 cropping and management combinations have been evaluated and others are being studied. Each combination has to be evaluated in segments (except established meadow retained for 1 year or more) to take into account different and succeeding periods

of the cropping year. The periods of the cropping year are: turn plow to seeding date, seeding to 30 days later, second 30 days after seeding, from 2 months after seeding to harvest, and harvest to turn plow or seedbed for the next crop. These periods were selected to represent the different cover or growth stages of the crop.

Similarly, the effect of meadow sod turned under before corn or cotton depends on the type and quality of the meadow and the fact that the residual effectiveness of the sod declines gradually for a period of 2 to 4 years after plowing. In another situation, the effectiveness of crop-residue management will depend on how much residue there is. And since the canopy protection of crops varies greatly in different months, an appropriate calendar distribution of erosive rains for any locality has to be established to measure this protection's effect on erosion. This information is supplied by erosion index distribution curves, like the one that is figure 3.

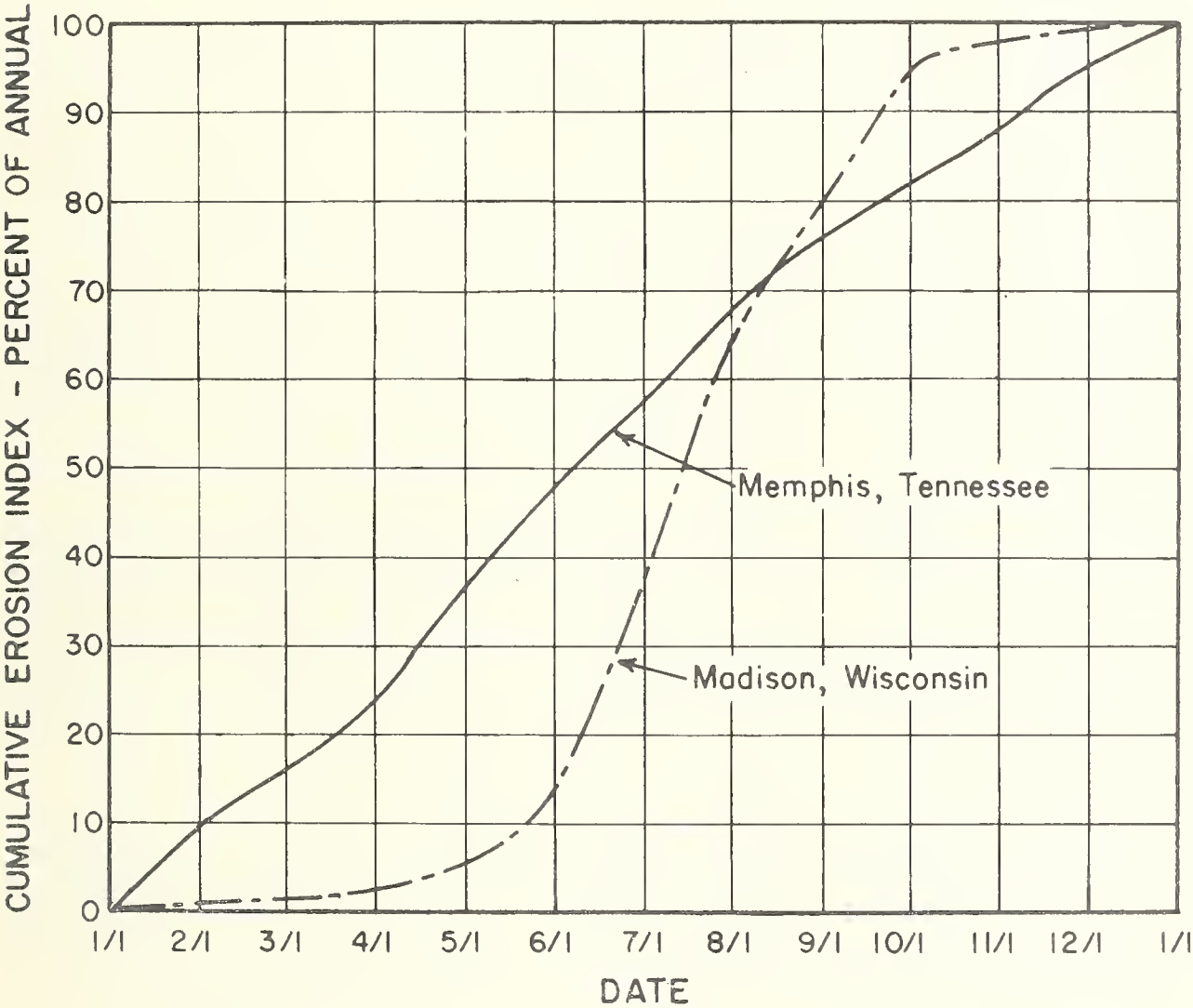

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Figure 3.--Chart showing how the average annual rainfall erosion index for a given locality may be distributed month by month as percentages. This is "Curve No. 1 for the Southeastern States" and is valid for all of Tennessee west of the Cumberland Mountains, northwestern Alabama, and all of Mississippi except the southeast corner. It is the one curve in the United States that most nearly approaches a straight line. Most location curves are some form of an S-shaped curve, such as the dashed-line curve, for Madison, Wis., shown on the chart.

The procedure for determining the C factor, developed by ARS scientists at Lafayette, takes these many variables into account. It is a combination of the effects of cropping and management and shows how these effects may be distributed through various months. Table 1 is a specific example. The cropping and management are a 4-year rotation of crops in the sequence oats-grass and legume meadow-corn-corn. Meadow yields average about 2 tons and corn about 45 bushels per acre, oat yields are low, and all grain and corn residues are left on the field.

TABLE 1.--Example of cropping and management factor evaluation.

(1)	(2)	(3)	(4)	(5)	(6)
Cropping and management	Soil-loss ratio[1]	Date each segment begins	Percent of annual erosion index: January 1 to date[2]	Percent of annual erosion index: Each segment[3]	Value of factor[4]
		8/1	66		
Meadow.....	0.[illegible]6	3/1	15	49	0.009
Meadow.....	.[illegible]6	3/1	15	100	
First corn					
Rough fallow.....	.15	4/1	24	[illegible]	
First 30 days after seeding.....	.32	5/1	35	11	
From 30 to 60 days after crop seeding.....	.30	6/1	46	11	
From 60 days after seeding to crop harvest...	.19	10/1	81	35	
From harvest to turnplow or next seedbed.....	.30	3/1	15	34	.25[illegible]
Second corn					
Rough fallow.....	.42	4/1	24	9	
First 30 days after seeding.....	.57	5/1	35	11	
From 30 to 60 days after crop seeding.....	.49	6/1	46	11	
From 60 days after seeding to crop harvest...	.28	10/1	81	35	.250
Oats					
First 30 days after oat seeding.....	.58	11/1	87	[illegible]	
From 30 days after seeding to April 1.....	.35	4/1	24	37	
From April 1 to grain harvest.....	.15	6/1	46	22	.1[illegible]
From grain harvest to 60 days thereafter.....	.03	8/1	66	20	.[illegible]
Total.....		4 years		400	.714
Annual average...				100	.179

[1] The expected ratio of soil loss from the specific crop and management to corresponding loss from cultivated continuous fallow on the same soil and slope and under the same rainfall.
[2] These values were obtained by reading the curve in figure 3 at each of the dates shown in column 3.
[3] Obtained from the values in column 4, by subtraction.
[4] The C factor is established by multiplying column 2 by column 5, line by line, and accumulating the partial products.

Source: "Soil Loss Estimation in the Southeast," a mimeographed report from an ARS-SCS workshop held at Athens, Ga., April 12-13, 1960.

As indicated, the total C factor is 71.4 percent. When divided by 4, this becomes 17.9 percent, which means that average annual soil losses from a field so cropped and so managed would be 17.9 percent of that to be expected from cultivated fallow on the same field.

The Conservation Practices Factor (P)

Values to measure the effects of conservation practices (contouring, stripcropping, and terracing, or certain combinations of these) were developed at a slope-practice workshop in Lafayette, Ind., in 1956. Data used came from experimental plots in LaCrosse, Wis., Bethany, Mo., and Urbana, Ill.

Contouring--plowing around hills rather than up and down them--is an inexpensive and effective conservation practice in the right places. Its effectiveness depends on row ridges, made with tillage implements, which retard water running down hill. Erosion from contoured fields may be from 100 percent to 50 percent of that expected from up-and-down tillage, depending on the steepness of slope. Contouring provides almost complete protection for individual storms of low intensity but for severe storms that cause excessive row breakage, it provides little or no protection.

In stripcropping, meadow strips alternate with grain strips and slow down the flow of water and catch soil eroded from the grain or cultivated strips. The usual cropping system is corn-small grain-2 years meadow. Erosion from stripcropped fields averages from 45 percent to 25 percent of that expected from up-and-down tillage, again depending on the steepness of slope.

Soil loss under contour stripcropping averages about 50 percent of that from contouring alone.

Terraces intercept the flow of water down the slope before it attains enough velocity to damage the land. They are a combination ridge and channel built across the slope on a controlled grade. Soil saved is due to the shortened slope length and deposition in the channel. If no credit is given for deposition in the terrace channel, contour factor values are used in the equation; if some credit is given, stripcrop factor values are used.

When computing the soil loss from a terraced field, the recommended horizontal spacing between terraces for a given percent of slope is the slope length used for determining the LS factor for use in the equation. The recommended horizontal terrace spacing is not the same for all soil-climatic areas, however. For example, for a 9-percent slope, in Tennessee, the recommended horizontal spacing is 53 feet but for the deep loess soils of southwest Iowa it is 82 feet.

Slope lengths for contoured and stripcropped fields are the full field slope length.

Soil Loss Tolerance (T) Values

Before the equation can be used to select practices, soil loss tolerance (T) values must be established for fields under study. These values are

the average annual soil loss that a farmer of these fields can tolerate and yet achieve the degree of conservation needed for sustained, economical production in the foreseeable future.

At the present time, T values are estimates. They may vary between 1 ton and 5 tons per acre depending on the type, depth, and quality of the soil in the field. T values usually appear in tables with K factors. Two values are generally given for each soil type depending on the degree of existing erosion in the field. For a given soil, moderately eroded, the T value might be 4 tons per acre. This means that a farmer with this type of soil must crop, manage, and use erosion controls in such a way that his average annual soil loss will not be greater than 4 tons per acre. The manner in which the equation might be used to define the cropping, managing, and erosion controls needed to achieve this objective is explained in the next section.

HOW THE EQUATION IS USED

The following examples show how the equation might be used in Maury County, Tenn. The following are given:

Maury County in western Tennessee has a rainfall erosion index (R factor) of 240.

The soil is a Maury silty clay loam; its erodibility (K factor) is 0.34.

The field slope length is 200 feet long and the average steepness of slope is 9-percent. The LS factor is therefore 1.7.

The cropping and management in recent years have been a 3-year rotation of wheat-meadow-corn, 40 bushels of corn per acre (residue left on the field) and 1 to 2 tons of hay per acre; the C factor is therefore 0.09.

Straight-row cultivation up and down slope has been practiced on this field, so the P factor, for the initial calculation, is 1.

The soil loss tolerance (T value) established for the soil of this field is 4 tons per acre per year.

Making the Initial Calculation

The field is initially assumed to be in tilled continuous fallow. Therefore, the factors whose effects must be initially considered are R, K, and LS--rainfall, soil erodibility, and length and percent of slope. Multiplying the listed values for these factors together shows that an average of 139 tons of soil per acre per year would erode from this field if it were tilled continuous fallow.

Modifying the Initial Calculation

But since the field as cropped and managed has a C-factor value of 0.09 the expected erosion would be only 9 percent of the 139 tons, or 12.5 tons per acre per year--still more than 3 times as great as the soil loss that can be tolerated. The problem now is to find the erosion controls that will reduce the expected annual soil loss to 4 tons per acre or less.

Contouring and Stripcropping Considered

The contouring P factor for a 9-percent slope is 0.60. This value times 12.5 gives 7.5 tons per acre--still nearly twice as great as the established tolerance.

Stripcropping plus contouring is now considered. This P factor value is 0.30 and 0.30 times 12.5 gives 3.8 tons per acre, which is within the annual soil loss tolerance established for this field. It is now shown that the farmer can continue the given cropping and management and still reduce his soil loss to realistic levels if he practices contoured stripcropping. The three-year rotation in this illustration is the minimum sod-based rotation adaptable to stripcropping. Addition of a second year of meadow so that a sod strip is below each grain strip and the corn and small grain strips are on separated fields provides a system better adapted to livestock farming while increasing the erosion control effectiveness of the system.

Terracing Considered

The P factor value for terracing plus contouring on a 9-percent slope is also 0.30 if we do not consider all soil deposited in the channel as lost, but slope length has to be changed to agree with the recommended horizontal terrace spacing, which, for a 9-percent slope, is 53 feet. The LS value for a 9-percent slope, 53 feet long, is 0.85, and this value is substituted in the initial calculation for 1.7. The initial calculation is now 69 tons--the average annual soil loss to be expected from this field, if terraced, that has a 9-percent, 53-foot slope in tilled continuous fallow. Multiplying 69 by 0.09 (C factor for the cropping and management given) and by 0.30 (P factor for a terraced, 9-percent slope) gives a final answer of 1.9 tons per acre--the average annual loss to be expected from this terraced, contour-farmed field.

Additional Approaches

If the farmer will not accept stripcropping or terracing, but will practice contouring, the problem is to select a cropping and management system that will keep soil loss within the 4 tons per acre per year. The initial calculation (R times K times LS) as modified by factor P (contouring) becomes 83 tons per acre--the average annual loss to be expected from this field when in tilled continuous contoured fallow.

The 83 value is now placed in a proportion, as follows: 83 : 1.00 = 4 : x. When the proportion is solved, x = 0.043, which is the maximum value for the C factor. The appropriate tables are now checked to find a cropping and management combination, similar to the original one, that has a C factor value approaching 0.043. A 4-year rotation of small grain-meadow-meadow-corn (residue left on the field), where the meadow is a grass-legume mixture yielding 2 to 3 tons per acre, and the corn yields 60 bushels per acre appears to be acceptable. It has a C factor value of 0.039. The field, of course, must be fertilized and managed in such a way that the listed yields will be realized.

These examples show how the equation can contribute significantly to safe, productive use of the Nation's soil. In the hands of qualified technicians, it is a flexible tool for defining the conservation practices needed for any field in the continental United States to limit rainfall-erosion losses to tolerable levels.

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Growth Through Agricultural Progress